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The Rise and Fall of the North Atlantic CO_2 Sink

Paul Halloran, Ian Totterdell, Matthew Mennary, Ben Booth, and Nick Dunstone
Met Office Hadley Centre, met Office, United Kingdom (paul.halloran@metoffice.gov.uk)

Over the last decade numerous observational studies have alluded to a declining, or at least highly variable, North Atlantic carbon sink. Analysis of ocean carbon cycle models has gone some way to explaining the high CO_2 variability observed in this region, but until now has been unable to explain the postulated historical decrease in the strength of the sink. Here we present results from the Met Office Hadley Centre's latest IPCC simulations which describe a strong increase in North Atlantic carbon uptake throughout much of the 1900's, rapidly switching to a decrease around the turn of the century.

Whilst the rate of change of atmospheric CO_2 concentrations continues to rise we broadly expect the rate of ocean CO_2 uptake to follow suit. Major marine physical and biogeochemical change may however regionally modify this pattern, influencing ocean CO_2 storage, and leading to a disconnect between anticipated and realised atmospheric CO_2 concentrations occurring in response to specific CO_2 emission scenarios. Both observational studies and atmospheric model inversions have suggested that changes are already occurring in the major marine CO_2 sinks, including the North Atlantic. If the postulated changes in ocean carbon storage are shown to be robust, it is imperative that earth system models are developed which can capture, explain and assess the future variability and impact of these changes. Using the Met Office Hadley Centre's latest Earth System model HadGEM2-ES we argue that the rise in North Atlantic CO_2 uptake since the preindustrial occurs in response to ocean circulation changes following volcanic and anthropogenic aerosol forcing, and that the recent decline in North Atlantic CO_2 uptake occurs as a readjustment to the reduction in European and North American aerosol emissions initiated in the 1980's.

Although the mechanisms linking volcanic and aerosol emissions to North Atlantic carbon uptake within the model are still under investigation, it appears that wind driven changes in Arctic Ocean circulation influence the salinity of water reaching sites of deep convection. Subsequent changes in overturning circulation impact the carbon-chemistry of water moving up the North Atlantic, in particular, elevating surface alkalinity. The elevated alkalinity and increased northwards advection of surface waters allow increased North Atlantic carbon uptake. A readjustment of Arctic circulation to the removal of aerosol-imposed forcings over recent years slows the northward flux of surface waters and drives a rapid decline in the strength of the North Atlantic Carbon sink.

The ensemble of model experiments in which we observe this response are not initialised or forced with any surface-ocean heat, wind-energy or precipitation fluxes, instead responding freely to reconstructed atmospheric greenhouse-gas and aerosol concentrations, natural (volcanic and solar) forcings and historical land-use change. Model ensemble members were initialised from periods in the free-running preindustrial climate experiment representing disparate phases of the ocean's internal variability. We therefore suggest that the unexpected carbon-uptake changes recently observed in the North Atlantic may represent a forced response to anthropogenic aerosol emissions, rather than a carbon cycle response to natural variability in the climate system.